Semi-automatic Segmentation of Vertebral Bodies in Volumetric MR Images Using a Statistical Shape+Pose Model

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Segmentation of vertebral structures enables quantitative analysis of spine pathologies.
- deformations caused by different pathologies
- slipped vertebra, herniate disk, disk/vertebra degeneration

Also has applications in image-guided interventions.
Challenges of MR Segmentation

- Poor contrast of bone structures.
- Variation in surrounding soft tissue contrast.
- Magnetic field inhomogeneity.
- Large inter-slice gap (around 4 mm) in typical clinical MR images compared to CT.
Related Work

- Most approaches are in 2D
  - [Egger’12], [Carballido-Gamio’04], [Shi’07], [Huang’09].

- 3D Methods are mostly evaluated on MR images with inter-slice gap of 1.2 mm or less.
  - [Kadoury’13], [Stern’11], [Neubert’12].

- Each vertebra is mostly segmented independently.
  - [Hoad’02], [Stern’11], [Neubert’12].
This Work

- We propose a method for simultaneous segmentation of multiple vertebrae.
- Registration-based segmentation technique.
- Alignment of a statistical multi-vertebrae model to MR images.
Statistical Shape Models

First four modes of shape variation

Mean shape  Transformation  PCA

Rasoulian et al., Group-wise registration of point sets for statistical shape models, TMI, 2012
Cootes et al., Active shape models-their training and application. Computer Vision and Image Understanding, 1995.
Multi-object models?

- Traditional approach is not working
  - Shape and pose are not correlated
  - Shape and pose do not belong to the same space

Bossa and Olmos, Multi-object Statistical Pose+Shape Models, ISBI, 2007.
Shape statistics

L1 Training set

Mean Shape and Variations

L2 Training set

Mean Shape and Variations

Concatenate the variations and perform the PCA
Shape variations

First Mode

Second Mode

Third Mode

Fourth Mode

N=32
Pose variations

- Pose are represented by similarity (rigid+scale) transformations

Mean Shapes
Similarity transformations form a Lie group


Pose variations

First Mode

Second Mode

Third Mode

Fourth Mode

N=32
Transformation of the model

- Transform the model by assigning weights to shape and pose modes of variations and a rigid transformation:

\[ s = \Phi(w_s, w_p, T) \]

- \(w_s\): weights for the shape variations
- \(w_p\): weights for the pose variations
- \(T\): rigid transformation
Statistical Shape+Pose Model

- Takes advantage of the correlation between shape and pose of different vertebrae in the same patient.
- Previously used for vertebra segmentation in CT\(^1\).
- We aim to find simple and fast pre-processing steps to adapt it to MR segmentation.

\(^1\) Rasoulian et al., TMI, 2013
Method

1. Intensity Correction
2. User Interaction
3. Anisotropic Diffusion
4. Model Registration
5. Canny Edge Detection
Pre-processing

- Intensity correction

Original image

Intensity-corrected image
User Interaction

- Mid-sagittal slice of intensity-corrected image is shown to the user.
- User clicks on each vertebra to start the segmentation process.
- Anisotropic diffusion and Canny edge detection is only applied on boxes centered to the clicked points.
Pre-processing

- Anisotropic diffusion

Intensity-corrected image

After anisotropic diffusion
Canny Edge Detection

- Extract edges in the boxes around points clicked by user.

Extracted edges using Canny edge detection on three slices of the same volume
Registration

- Register the multi-vertebrae anatomical model to the edge map using an iterative Expectation Maximization (EM) method.
- Only vertebral body part of the model is used for registration.
Registration on mid-sagittal slice
Registration

Registration on mid-sagittal slice
Segmentation Results

- Evaluated on nine multi-slice MR images.
- Inter-slice gaps in range of [3.3 mm 4.4 mm].
- Manual segmentation is used as ground truth.
- Computation time: less than 2 minutes on a 2.5 GHz Intel core i5 machine.
- 3D mean surface error $\approx 3 \pm 0.8$ mm.
- 2D mean error in mid-sagittal slices $\approx 1.9 \pm 0.4$ mm.
Examples of segmentation results in five different volumes
Conclusions

- A method for semi-automatic simultaneous segmentation of vertebral bodies in volumetric MR images is proposed.

- Future work includes
  - Segmentation of whole vertebrae.
Next Step

- Automatic localization of vertebrae instead of user interaction.
Acknowledgement
Thank you ...